High Sensitivity Broadcast TV Signal Detection

Mark McHenry
Alexe Leu
Karl Steadman
Shyam Chunduri
Jim Bates
Felix Mihai
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Shared Spectrum Company
8133 Leesburg Pike, Suite 220
Vienna, VA 22182-2706

703-761-2818
fax: 703-761-2817

www.sharedspectrum.com

1. Table of Contents

2. Introduction

2.1 Report Scope

The purpose of these tests is to validate that both analog and digital TV signals can be detected significantly below the thermal noise level. The ability to detect TV signals below the thermal noise level is a critical element of future spectrum sharing in the television band.

Shared Spectrum Company has developed a feature detector test bed that allows off-the-air signals with frequency from 30 MHz to 3000 MHz to be measured using feature detection methods. Signals are down converted and digitized at IF frequencies for post processing, and signals can be detected in real time using an FPGA board-based feature detector. This system can be easily used to demonstrate the performance of feature detectors on TV signals.

2.2 Use of Ultra Sensitive Detectors in Dynamic Spectrum Sharing Approach

A key feature of Listen-Before-Talk spectrum access methods is the use of an ultra-sensitive detector to identify unused spectrum. For sharing in the TV bands, the goal is to use a detector that is much more sensitive (30 to 50 dB) than a TV receiver. Better detector sensitivity reduces interference and enables higher transmit power levels.

Intel’s comments provides an estimate of the digital TV pilot signal detection threshold of -129 dBm. We believe that this is a reasonable threshold value.

2.3 Technical Issues

There are several technical issues that these field measurements resolve. These include:

- The effect of finite time stability of long (>100 km), terrestrial, propagation paths, which limit the amount of achievable coherent integration,
- The presence of spurious signals in the TV bands that would mask or confuse a feature detector,
- The effect of limited RF front-end dynamic range and the creation of undesired internal spurious signals that mask or confuse a feature detector,
- The suitability of TV signal waveforms for use with feature detectors.

2.4 TV Signal Detector Types

SSC investigated both cyclostationary detectors and FFT-type feature detectors to detect weak TV signals. This report provides describes the FFT-type detector performance. These offer computational and detection performance advantages compared to cyclostationary detectors in this situation.

3. Measurement Sites

Measurements were made at four locations as described below.

3.1 Shared Spectrum Company Offices

Measurements were made inside the Shared Spectrum Company offices in Vienna, VA. This location has multiple PC computers and printers, and is a typical office environment. Because of the large number of electronic devices, it has significant RF noise. Figure 1 shows the location and Figure 2 shows a photograph of the environments.

Figure 1. Map Showing Location at SSC Office

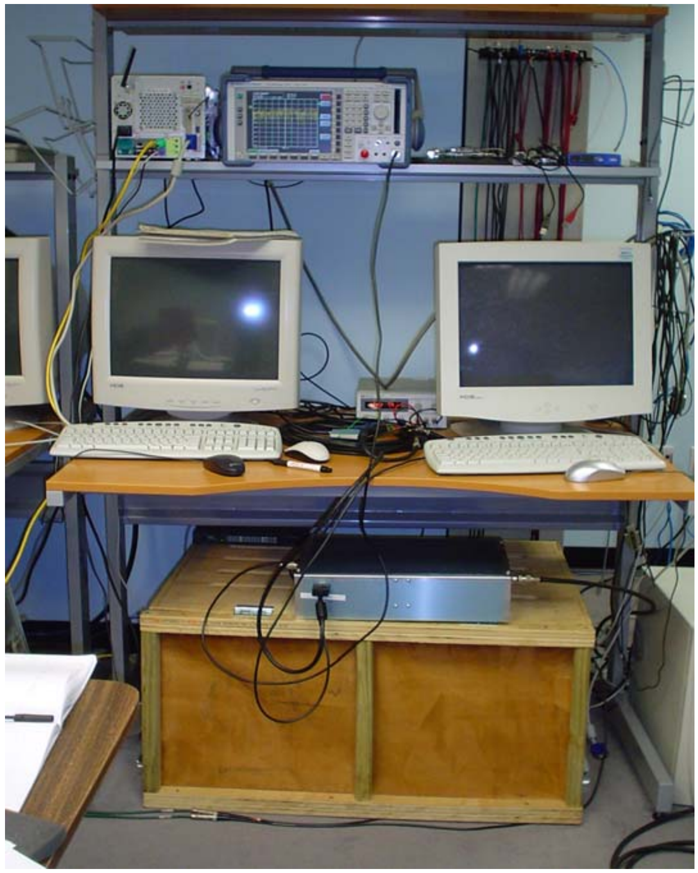


Figure 2. Laboratory Equipment at SSC Offices

3.2 Suburban Residence (McLean, VA)

Measurements were made at a residential location in McLean, VA. The equipment was connected to a standard TV antenna located on the second story roof. Figure 3 shows a photograph of the environment.

Figure 3. Suburban residence in McLean VA.

3.3 Riverbend Park, VA

Figure 4 shows the location of measurements in a rural location in Northern Virginia and in Figure 5 is a photograph of the environments.

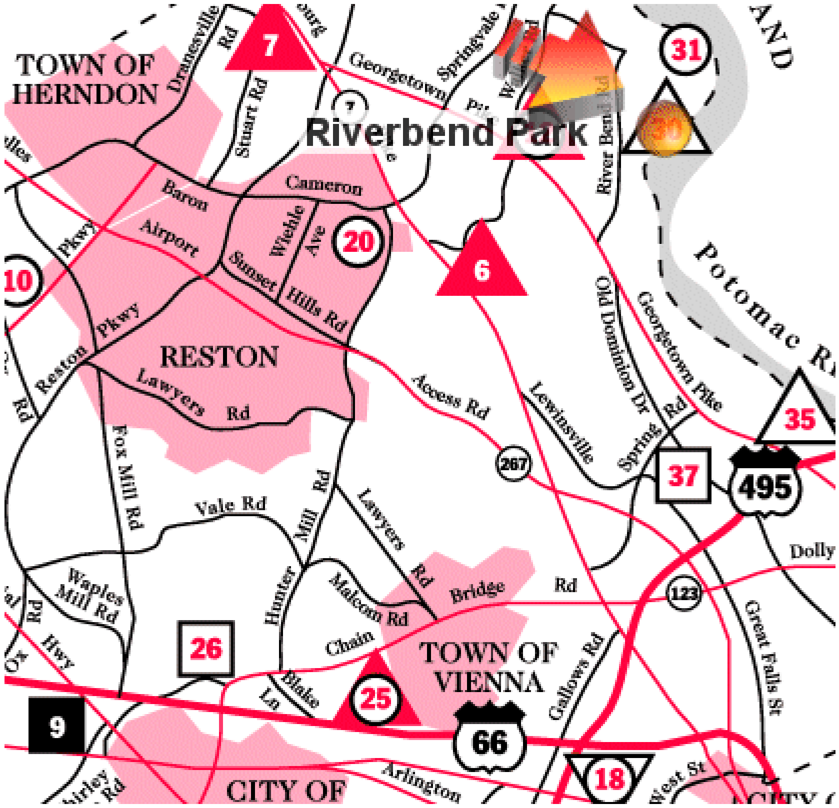


Figure 4. Map Showing Location of Riverbend Park

Figure 5. Riverbend Park, Fairfax County, VA

3.4 National Radio Astronomy Observatory, West Virginia

Spectrum measurements were made at the National Radio Astronomy Observatory at Green Bank, West Virginia. The purpose was to measure spectral usage in a quiet, low radio noise, low interference environment. The National Radio Quiet Zone (NRQZ) minimizes possible interference. For example, to reduce spark plug noise, only diesel vehicles are used on the site. Figure 6 shows the location and Figure 7 shows the environment.

Figure 6. Map showing NRAO, Green Bank, WV Site

Figure 7. NRAO Green Bank, WV Campus and Telescope

4. Measurement Equipment

This section describes the measurement equipment.

4.1 Equipment Used

The measurement equipment consists in:

- An omni-directional antenna (Discone).
- Coaxial cables connecting the antennas to the Pre-Selector box.
- The Pre-Selector box.
- A 20-foot long RG8 cable connecting the Pre-Selector box to the shielded enclosure.
- A shielded enclosure containing the Spectrum Analyzer, power supplies and a laptop computer.
- A 120VAC extension cord connecting the enclosure to an AC outlet. In some locations the equipment was power by a shielded gasoline powered generator or batteries.

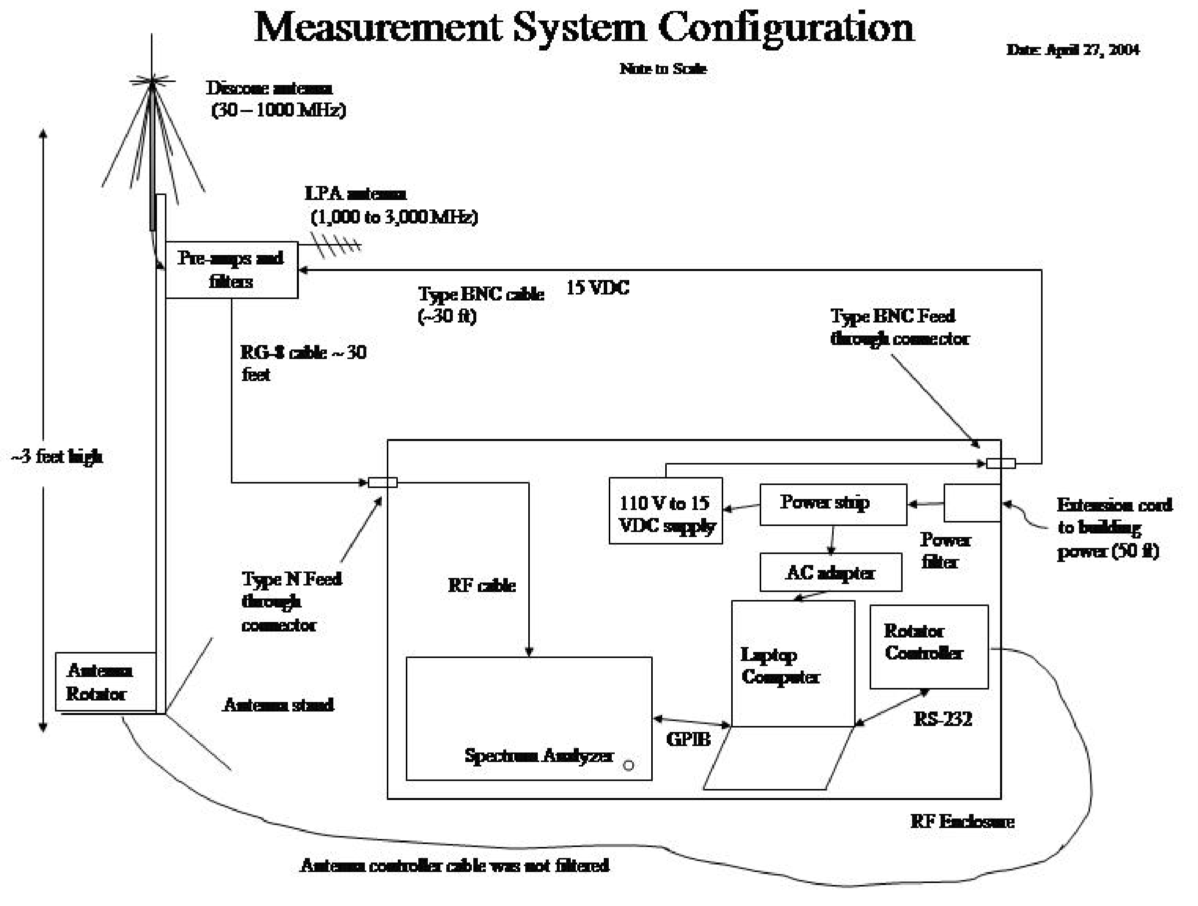


Figure 8. Spectrum Measurement Equipment Configuration

4.2 Preselector diagram

The preselector allowed remote automated configuration of antennas, filters, amplifiers and attenuators. Only the upper portion with a single antenna was used in these measurements.

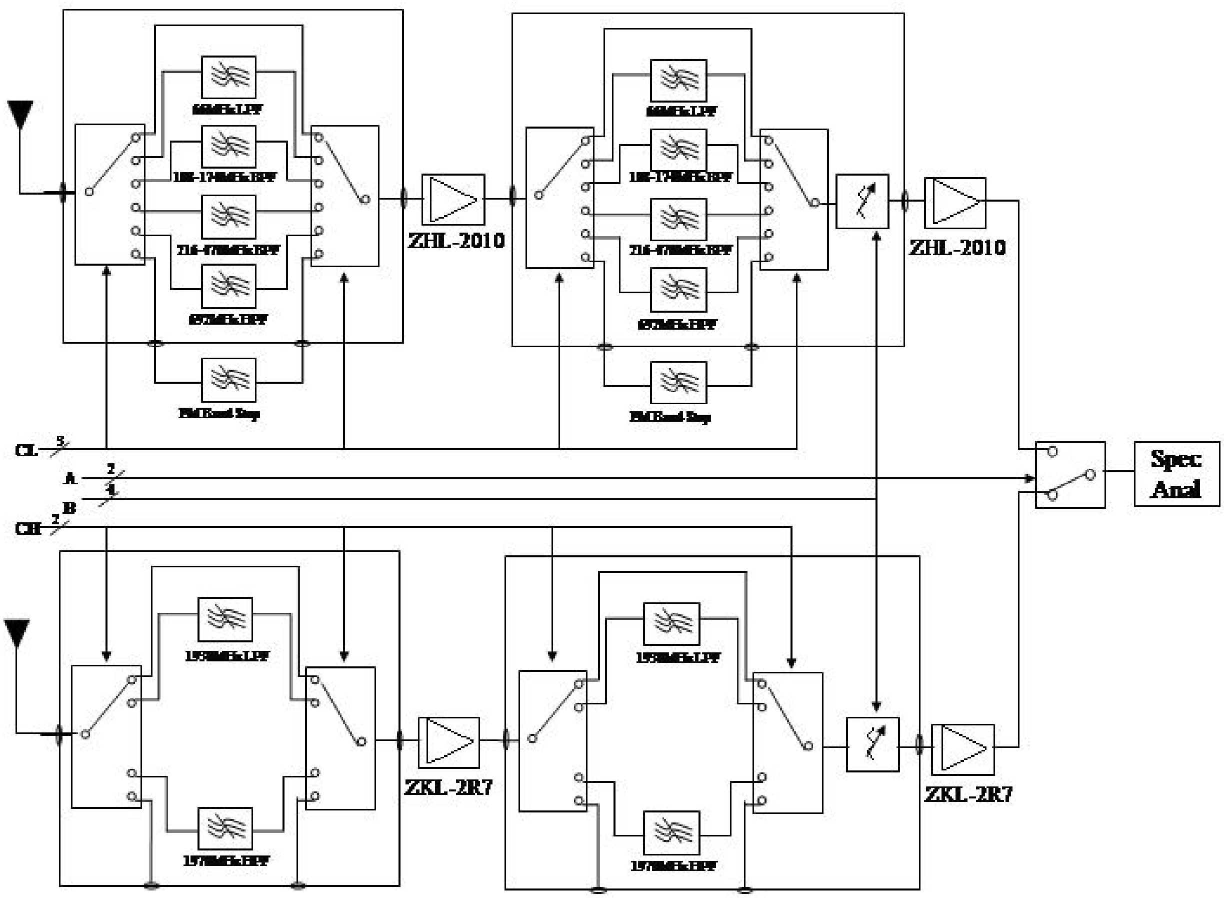


Figure 9. Preselector Diagram

4.3 RF Signal Path

RF from the antenna is converted to an intermediate frequency and then digitzed and saved to a file. The data in the file was then analyzed and plotted.

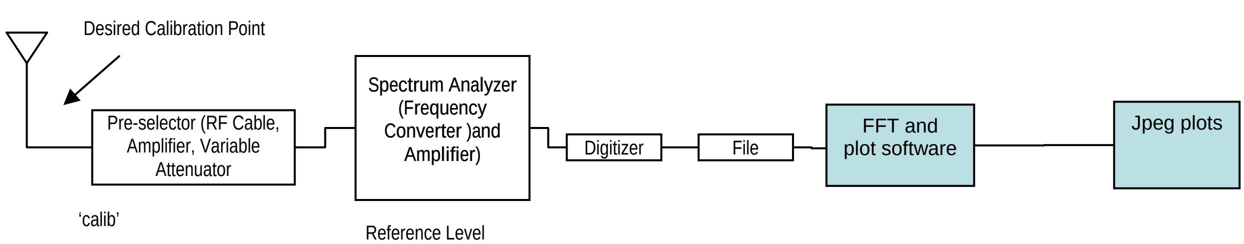


Figure 10. RF Signal Chain

4.4 Signal Digitization

In Figure 11, the detector processor receives a downconverted RF signal at a 20.4 MHz IF, using a spectrum analyzer. This 20.4 MHz IF is sampled at 58.5 Mega-samples/second and digitized at 14 bits of accuracy. Within a Virtex FPGA the signal is filtered and downconverted to baseband. The FPGA processor generates 90 thousand complex samples per second.

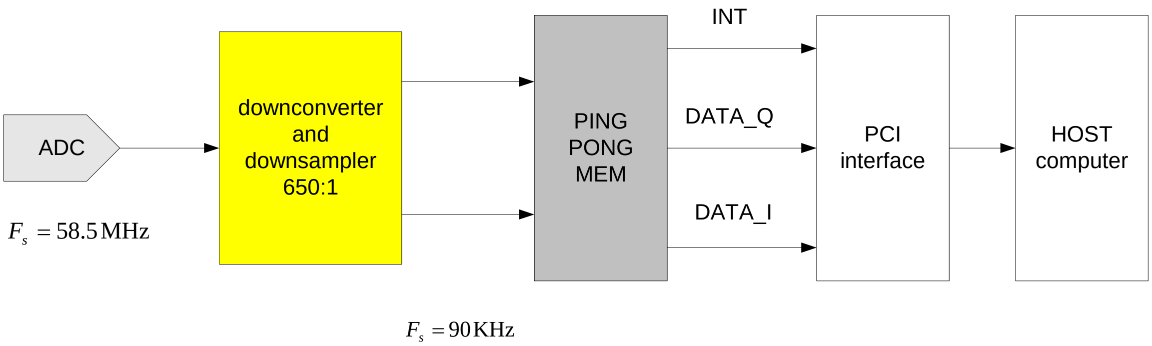
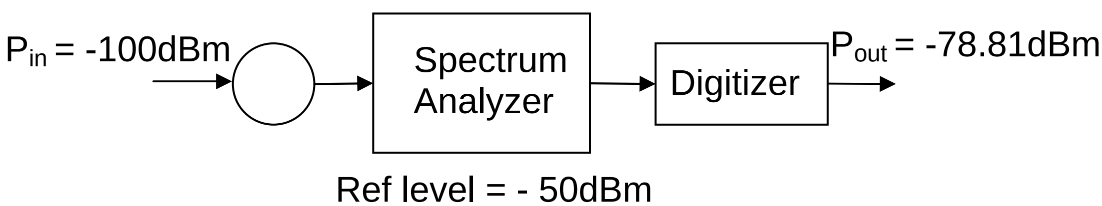


Figure 11

The detector's processor performs a FFT on data sampled about 45 kHz either side of a centered TV carrier frequency for each of the 2 to 69 allocated TV channels.

4.5 Calibration

The RF signal path was calibrated over all frequencies and pre-selector configurations. The configuration below used a test tone at -100 dBm to calibrate the digitizer.



4.6 TV Channel Frequency Lists

Digital (ATSC) Carrier (pilot) and Analog TV (NTSC) Video Carrier Frequencies are listed below.

Channel	Center Freq (MHz)	NTSC Carrier (MHz)	ATSC Pilot (MHz)		Channel	Center Freq (MHz)	NTSC Carrier (MHz)	ATSC Pilot (MHz)
2	57	55.25	54.30944		36	605	603.25	602.3094
3	63	61.25	60.30944		37	611	609.25	608.3094
4	69	67.25	66.30944		38	617	615.25	614.3094
5	79	77.25	76.30944		39	623	621.25	620.3094
6	85	83.25	82.30944		40	629	627.25	626.3094
7	177	175.25	174.3094		41	635	633.25	632.3094
8	183	181.25	180.3094		42	641	639.25	638.3094
9	189	187.25	186.3094		43	647	645.25	644.3094
10	195	193.25	192.3094		44	653	651.25	650.3094
11	201	199.25	198.3094		45	659	657.25	656.3094
12	207	205.25	204.3094		46	665	663.25	662.3094
13	213	211.25	210.3094		47	671	669.25	668.3094
14	473	471.25	470.3094		48	677	675.25	674.3094
15	479	477.25	476.3094		49	683	681.25	680.3094
16	485	483.25	482.3094		50	689	687.25	686.3094
17	491	489.25	488.3094		51	695	693.25	692.3094
18	497	495.25	494.3094		52	701	699.25	698.3094
19	503	501.25	500.3094		53	707	705.25	704.3094
20	509	507.25	506.3094		54	713	711.25	710.3094
21	515	513.25	512.3094		55	719	717.25	716.3094
22	521	519.25	518.3094		56	725	723.25	722.3094
23	527	525.25	524.3094		57	731	729.25	728.3094
24	533	531.25	530.3094		58	737	735.25	734.3094
25	539	537.25	536.3094		59	743	741.25	740.3094
26	545	543.25	542.3094		60	749	747.25	746.3094
27	551	549.25	548.3094		61	755	753.25	752.3094
28	557	555.25	554.3094		62	761	759.25	758.3094
29	563	561.25	560.3094		63	767	765.25	764.3094
30	569	567.25	566.3094		64	773	771.25	770.3094
31	575	573.25	572.3094		65	779	777.25	776.3094
32	581	579.25	578.3094		66	785	783.25	782.3094
33	587	585.25	584.3094		67	791	789.25	788.3094
34	593	591.25	590.3094		68	797	795.25	794.3094
35	599	597.25	596.3094		69	803	801.25	800.3094

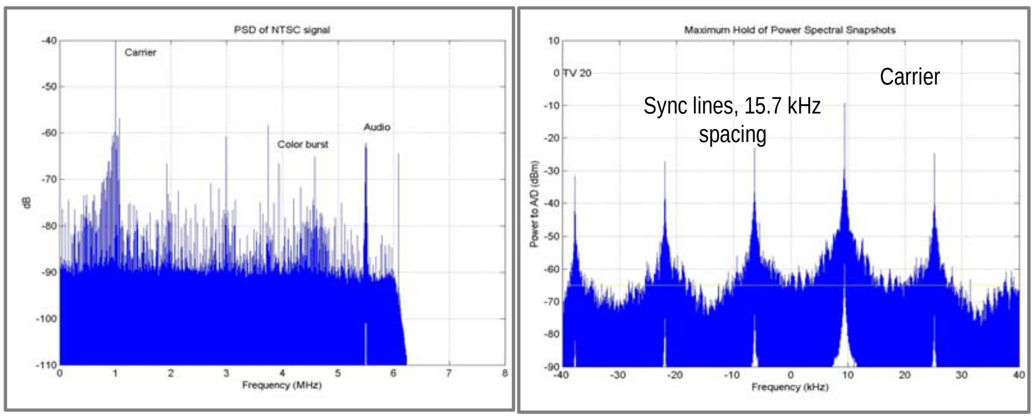
5. Broadcast TV Signal Characteristics

This section describes the NTSC (analog) and ATSC (digital) TV signals.

5.1 NTSC (Analog) Signal Characteristics

Figure 12 shows that entire 6 MHz NTSC spectrum and a 90 kHz close-up of the carrier region.

NTSC TV Signal Format



6 MHz span 90 kHz span

Video carrier offset by +10 kHz

Figure 12. NTSC TV Signal Format

The standard analog TV video carrier frequency is 1.25 MHz above the lower limit of the 6 MHz channel. Depending on the station's power and its distance from other TV stations on the same channel, the video carrier can be set to:

- The "standard" frequency,
- 10 kHz above the "standard" frequency or
- 10 kHz below the "standard" frequency.

Low power analog TV stations have different rules. Apparently they can put their video carrier anywhere between minus 10 kHz and plus 10 kHz in relation to the standard carrier frequency.
The horizontal sync pulse appears at 15,734Hz above and below the carrier frequency.
Horizontal sync pulse harmonics appear at multiples of 15,734Hz above and below the carrier frequency.
The sync pulses should be 15dB to 25 dB below the video carrier.

The carrier power contributes approximately 25% of the total signal power. Thus, the difference between the measured carrier power level is 10*log10(.25)=- 6 dB.   Example: Carrier measured at -100 dBm has a signal power of -94 dBm.

5.2 ATSC (Digital) Signal Characteristics

Figure 13 shows shows that entire 6 MHz ATSC spectrum and a 90 kHz close-up of the pilot region.

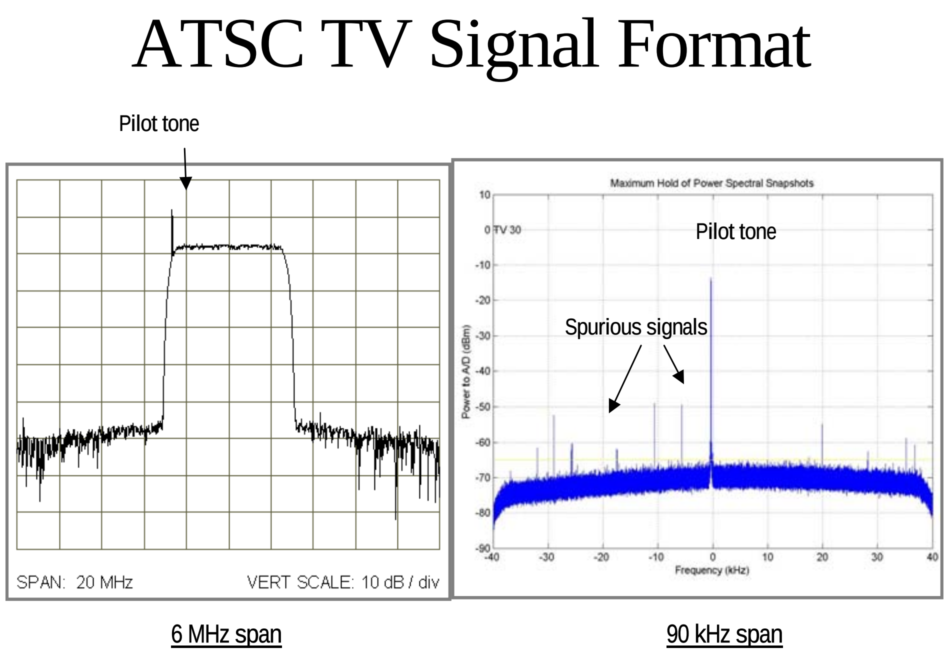


Figure 13. ATSC TV Signal Format

5.2.1 ATSC (Digital) Spectrum Analysis

The 6 MHz wide digital TV channel is the same width and is the same channel that is used for analog TV. When viewed on a spectrum analyzer the digital TV pilot (carrier) appears at 309.44 kHz above the lower channel limit. The pilot appears to be stronger than the signal that represents the digital information. The digital information looks like wideband noise that is all the same strength on the spectrum analyzer. Like some low powered analog TV stations, some digital pilot frequencies are in different offsets on the 6 MHz channel.

The ATSC pilot contributes 0.3 dB to the total signal power. Thus, the difference between the measured carrier power level is 10*log10(1-10^0.03) = -11.45 dB. Example: Pilot measured at -100 dBm. Thus the signal power is -88.55 dBm.

6. Measurement Results

This section provides a summary of the measurement results.

6.1.1 Example Analog TV Signal Detection Measurements

Figure 14 shows 90 kHz of the spectrum of TV Channel 45 received at Green Bank, WV. This is a three dimensional plot of consecutive FFT rows (3-D FFT plot) to illustrate the signal fluctuations and the presence of the spurious signals over time and frequency. Since the size of the FFT was too large (207,447 bins), we retained only the maximum value for every 10 bins, to decrease the size of the data 10 times. However, in Figure 14 the pilot of the existent NTSC signal in TV channel can be seen at the corresponding frequency of 657.3 MHz. The amplitude of the pilot is the highest varying over time between -160 dBm to -14 dBm, such that it will not be difficult to be detected using a threshold level of -150 dBm.

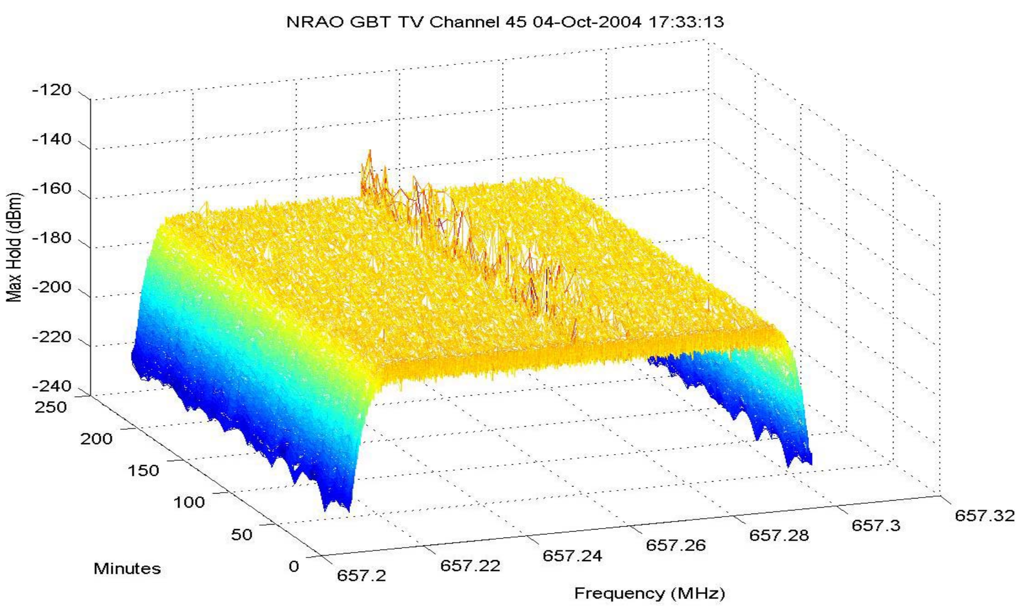


Figure 14. "3-D plot" Weak Analog TV signal with minimal spurious signals

Similarly, Figure 15 shows 90 kHz of the spectrum of TV Channel 58 received inside SSC Office, McLean VA. In this band there is locally a NTSC TV signal with a carrier frequency at 735.3MHz. We can observe the sync pulse harmonics that appear 15 dB to 25 dB weaker than the amplitude of the video carrier. There also numerous spurious signal amplitudes up to -110 dBm are present in the figure, which we will discuss later in this section. However, this plot shows that the NTSC signal, existent in the channel 58, is more difficult to be detected with a threshold level below -115dBm.

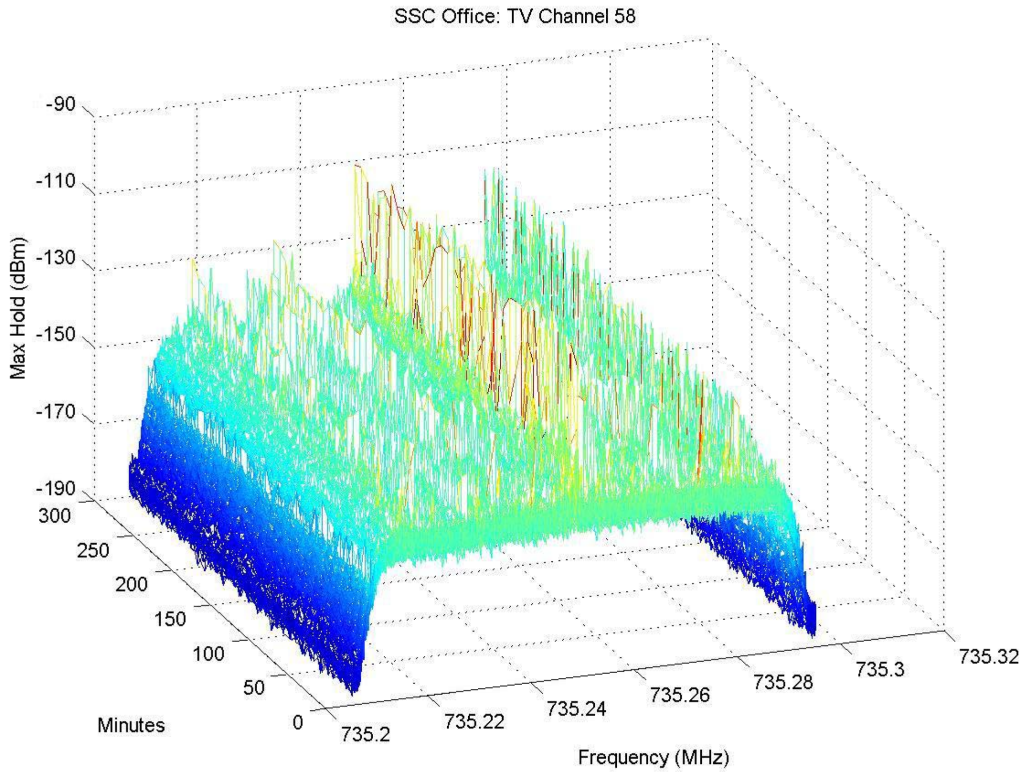


Figure 15. "3-D plot" TV channel 58 in SSC Office

Further, we describe the spectrum around the carrier of this channel based on a second plot Figure 16 called "Max-Hold/Waterfall/Duty cycle", which consists in three subplots:

- The "Max Hold" plot shows the maximum amplitude (over the entire collection period) versus frequency.
- The "Waterfall" plot shows the presence of signal amplitude above a threshold versus frequency.
- The "Duty Cycle" plot shows the fraction of time that the signal amplitude is above the threshold versus frequency.

The "Max Hold" plot for channel 58 shows the video carrier at 735.3 MHz having a signal level of -104 dBm. The sync pulse harmonics are separated by 15,734 Hz. The sync pulses appear 15 dB to 25 dB weaker than the video carrier. The noise floor appears at -150 dBm. The video carrier at the appropriate frequency and four of the sync pulses (two on each side of the carrier) are enough to identify the signal as an NTSC TV signal.

The "waterfall" plot shows the maximum signal during each sample period of more than 200 minutes of monitoring. This confirms that the carrier and sync pulses appear on the same frequency throughout the samples.

The "Duty Cycle" plot indicated how many samples contained an exact frequency. This shows that in the FFT rows the carrier and sync pulses appear more than other spurious signals. The carrier shows at the frequency 735.25 where the duty cycle is around 0.75. The left and right first sync pulse harmonics are at approximately 735.236 MHz and 735.265 MHz, respectively. The duty cycles are both around 0.15. Since the FFT frequency bin resolution is 0.43 Hz, the duty cycle is very sensitive to frequency drifts.

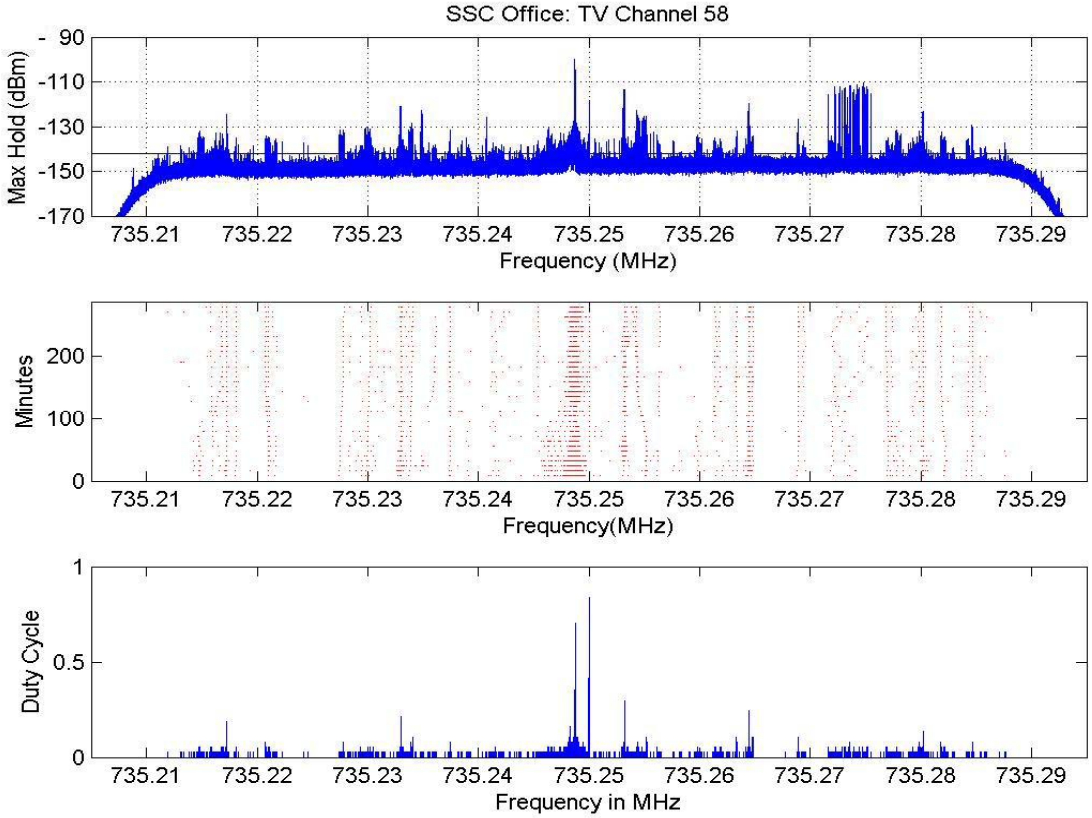


Figure 16. "Max-Hold" plot for TV channel 58 in SSC Office

6.1.2 Digital TV Signal

Figure 17 shows channel 39 received at Green Bank, WV. The pilot (carrier) appears at approximately 620.3094 MHz with the amplitude fluctuating around -155 dBm as it can be seen in Figure 18. The noise floor is at - 160 dBm. Channel 39 is the channel allocated for digital (ATSC) signal by the FCC, which can be detected with a threshold as very low as -156 dBm.

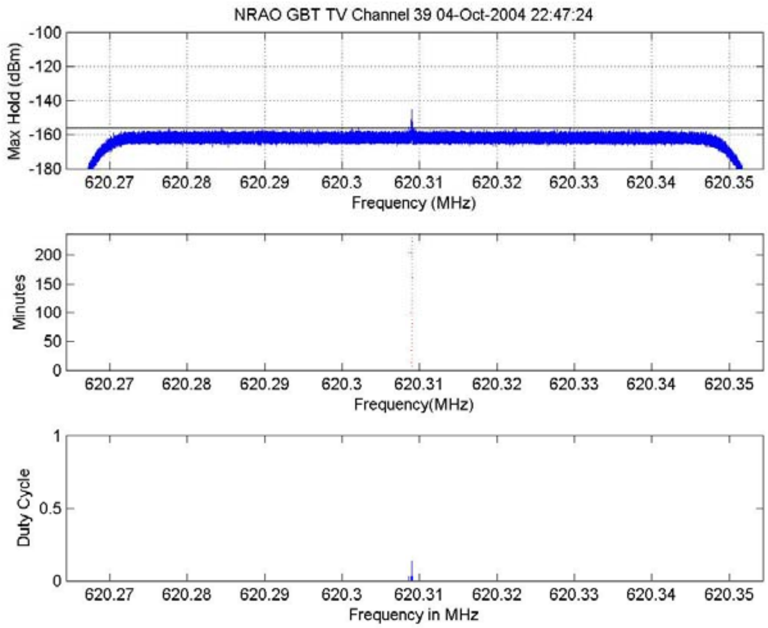


Figure 17. "Max-Hold" Weak ATSC signal with minimal spurious signals

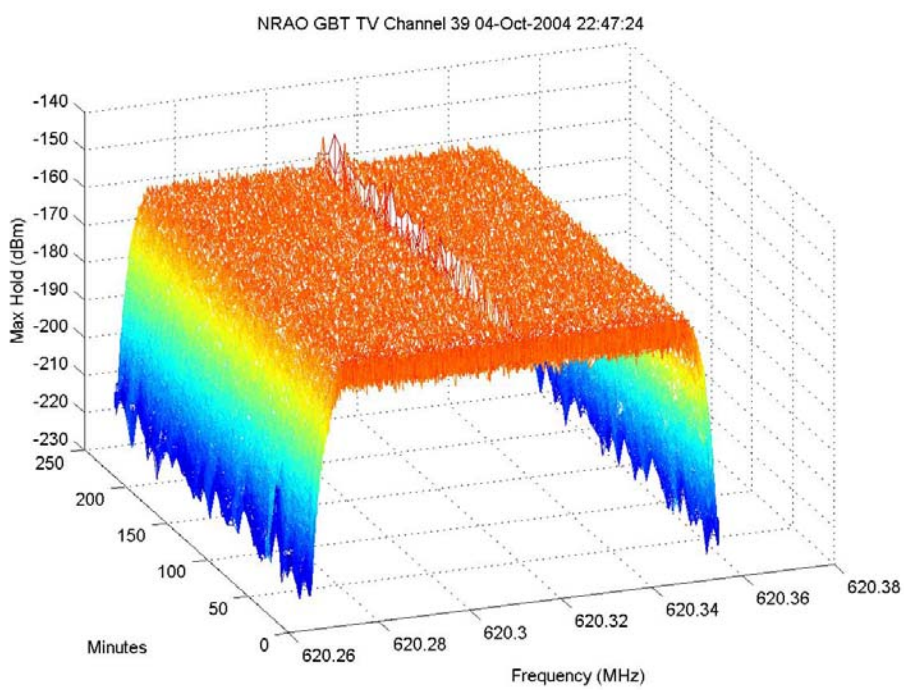


Figure 18. "3-D plot" weak ATSC signal with minimal spurious signals

Error! Reference source not found. shows a digital pilot at 500.30944 MHz received at Green Bank on Channel 19.

The purpose of this plot is to show that a very weak ATSC (digital) pilot is detectable.

In Figure 19, there is plotted the spectrum around the pilot of the ATSC signal in channel 27. Due to the relatively high levels of the spurious signals, the threshold for detection can not be lowered below -121 dBm. This is perceived as a limitation of the detector with respect to the capability of avoiding the interference created to the TV receivers.

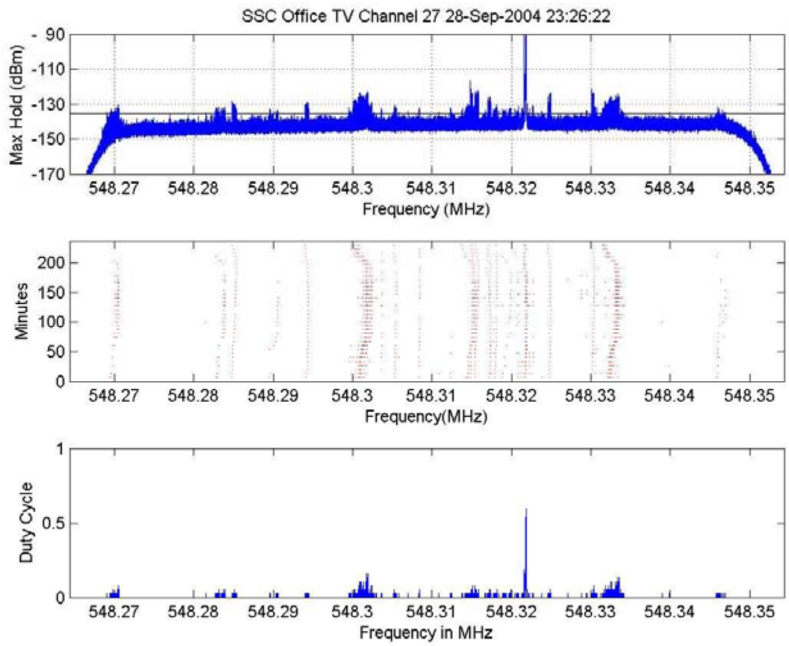


Figure 19. "Max-Hold" weak ATSC signal hard to identify with low threshold levels

6.2 Spurious Signals

In Figure 16, corresponding to a NTSC signal in channel 58 received in SSC office, we can notice the following types of spurious signals:

- Discrete in frequency domain and continuous in time, distributed over the entire band.
- Discrete in frequency domain, continuous in time and slowly drifting their frequencies;
- Discrete in frequency domain, impulsive in time and rapidly drifting their frequencies. This type of spurious signals appear within the band of 735.272MHz to 735.275MHz.

In Figure 19, corresponding to the ATSC signal in channel 39 received in SSC office, we can see 3 kHz bandwidth spurious signals, continuously present in the band and slowly drifting in frequency domain. There are noticed three such signals equally separated in frequency.

6.3 Achievable Detector Sensitivity

The achievable detector sensitivity depends on the strength of the TV carrier and pilot signals and the strength of the spurious signals observed at each location. The following figures shows the maximum TV signal amplitudes (during the the several hour observation period) and the amplitude of the spurious signals.

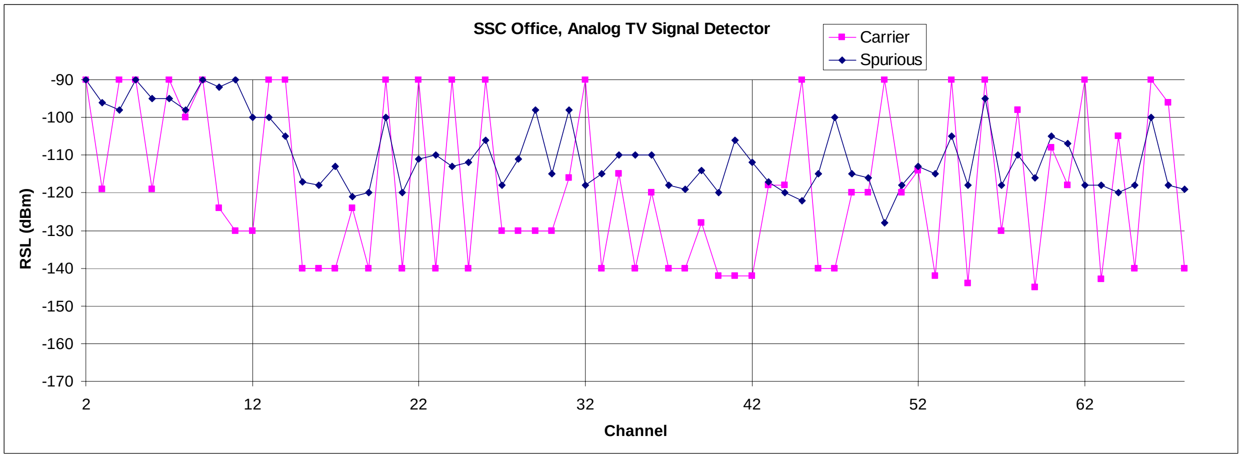


Figure 20. Measurement in SSC Office, Analog TV Signal Detector

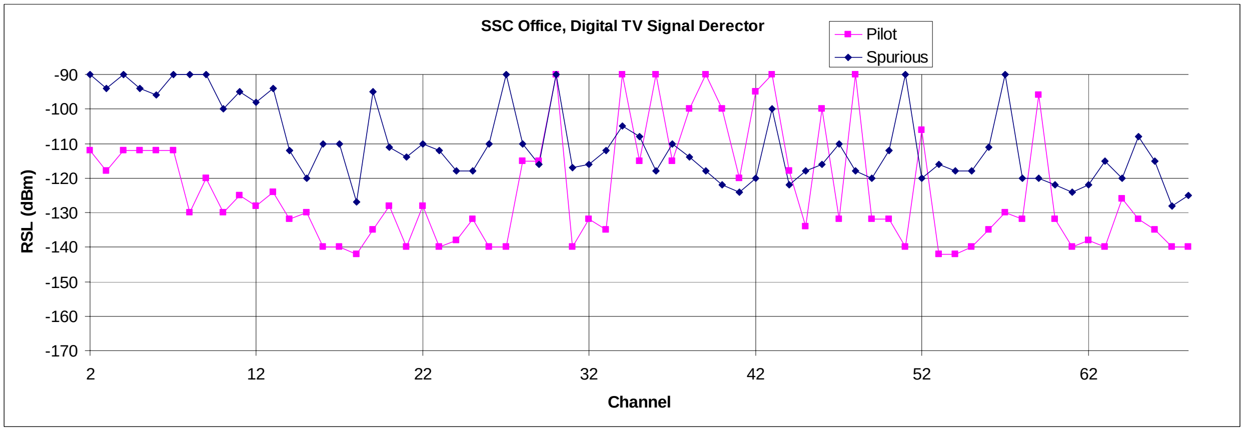


Figure 21. Measurements in SSC Office, Digital TV Signal Detector

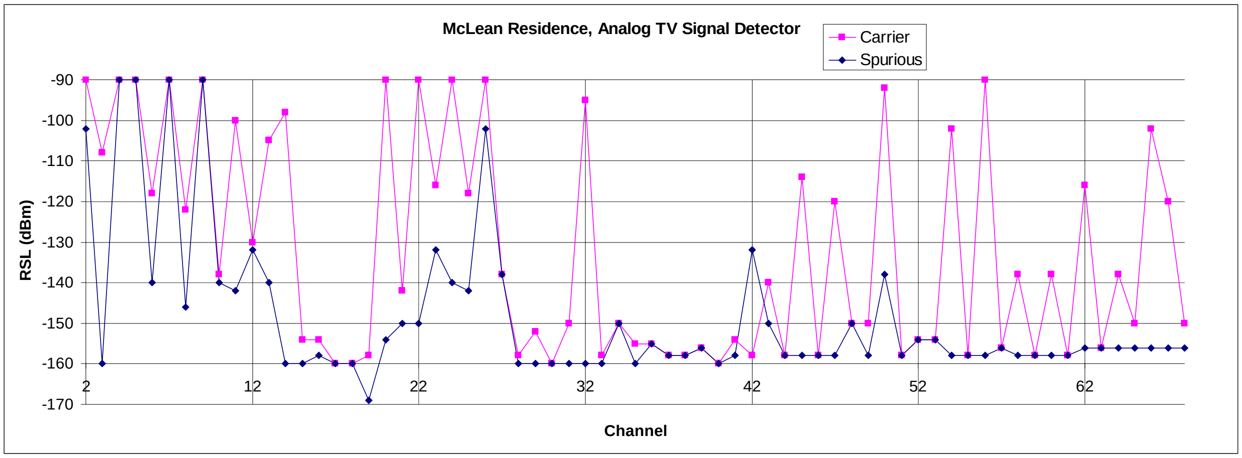


Figure 22. Measurement in McLean, Analog TV Signal Detector

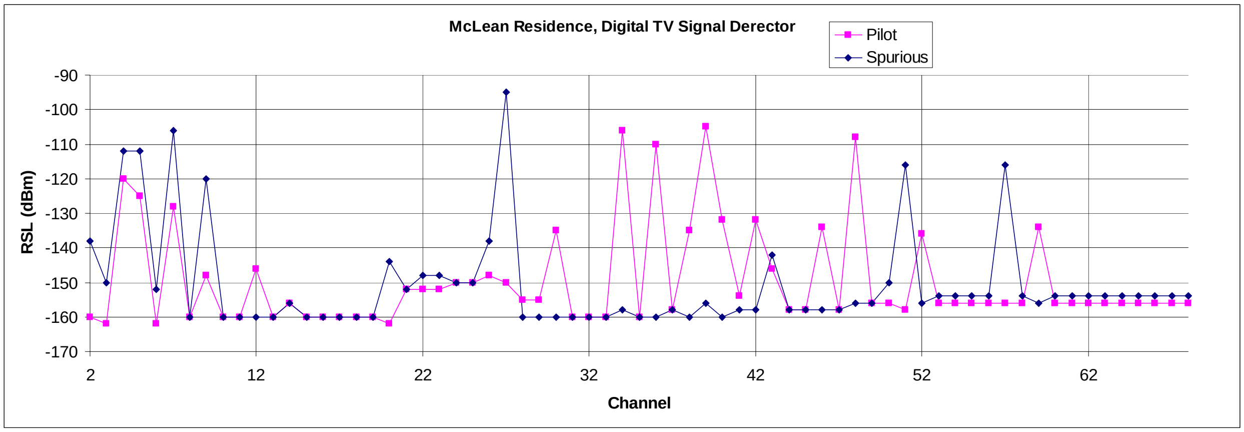


Figure 23. McLean Residence, Digital TV Signal Detector

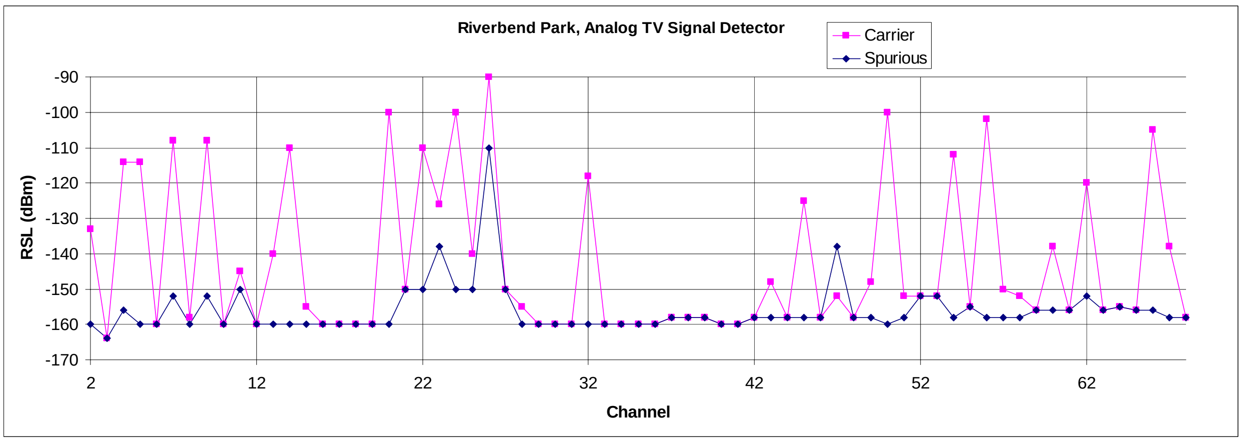


Figure 24. Riverbend Park, Analog TV Signal Detector

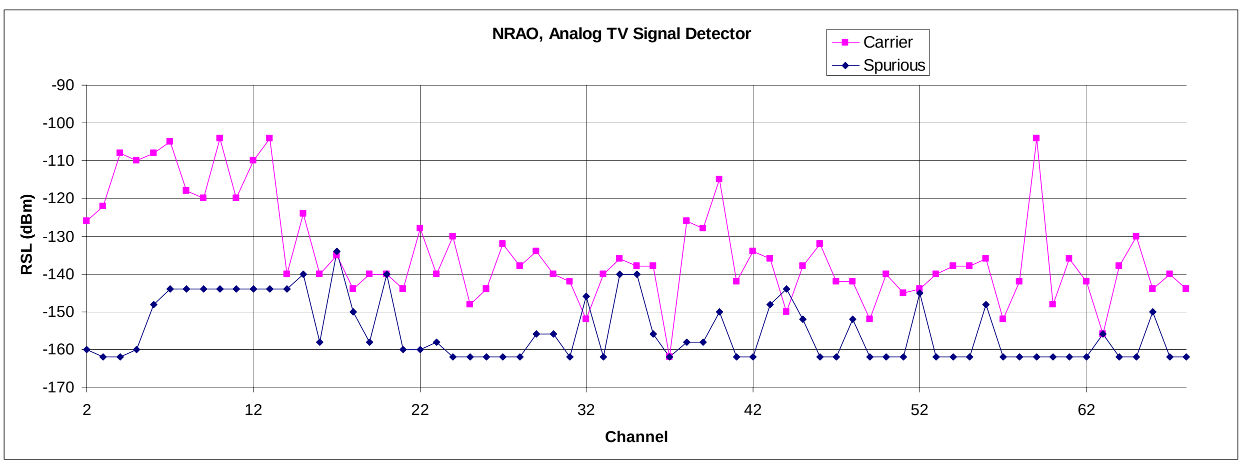


Figure 25. NRAO Analog TV Signal Detector

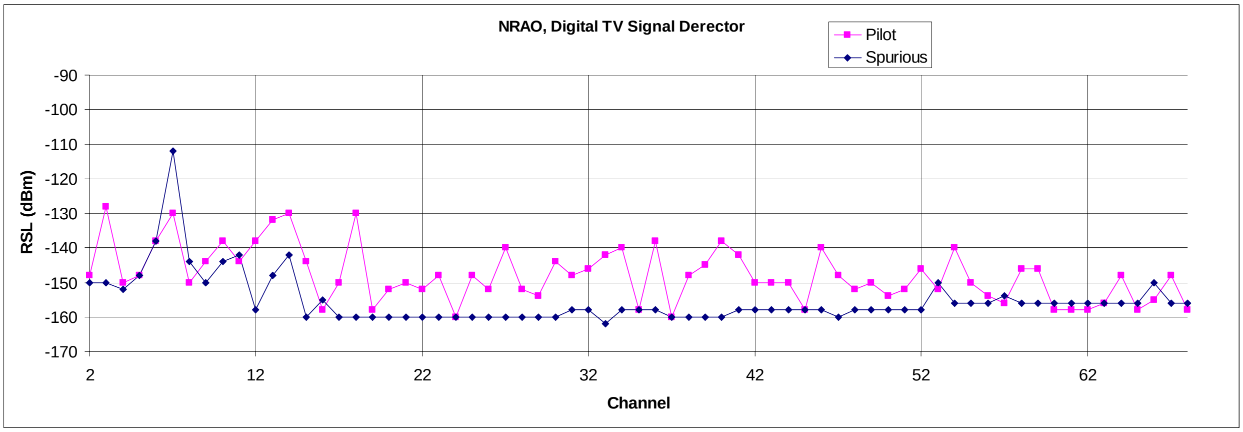


Figure 26. Measurements in NRAO, Digital TV Signal Detector

6.4 Signal Amplitude Fluctuation versus Time

The carrier and pilot signal amplitudes were found to fluctuate significantly versus time. In Figure 27 there is an example of strong NTSC signal in TV band 26. From the plot, it can be noticed that the signal fluctuates within a range of 20 dB. The fluctuation period is around 30 minutes.

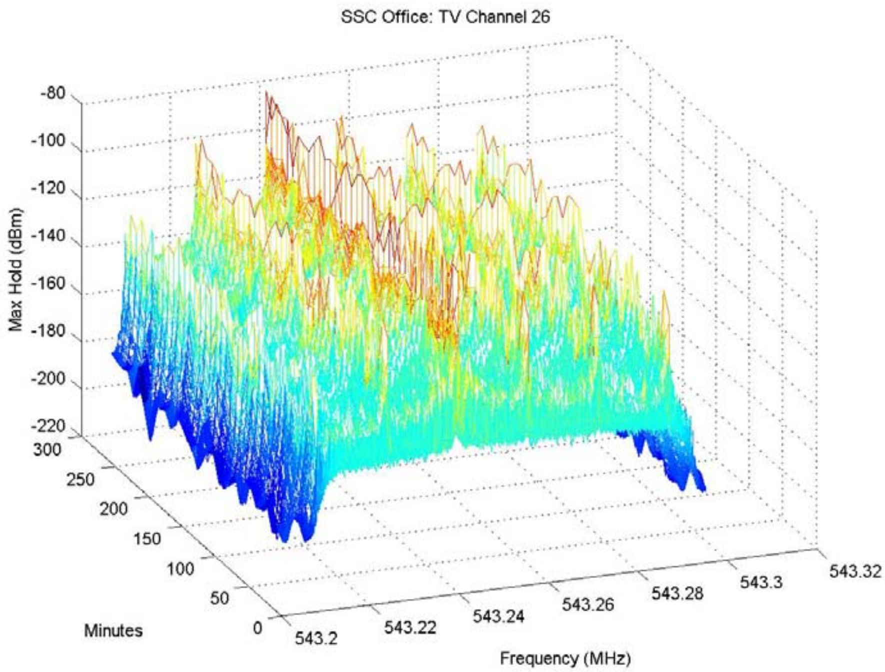


Figure 27. "3-D plot" TV channel 26 measurements in SSC office, Analog TV Detector

In Figure 28, there is an example of weak NTSC signal in TV band 23. The signal fluctuates within a range of 30 dB at a higher rate than the strong signal. The fluctuation period is approximately 10 minutes.

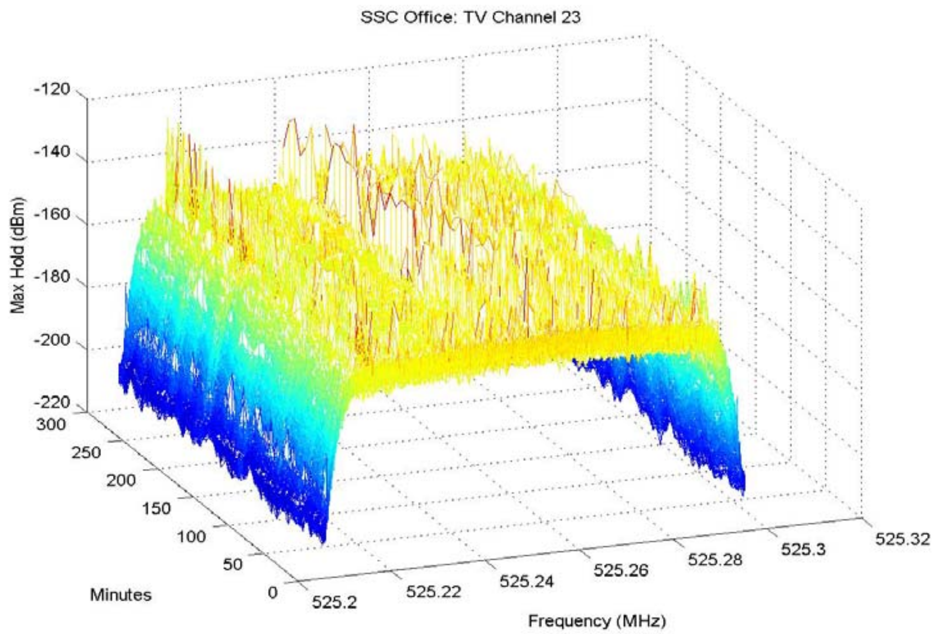


Figure 28. "3-D plot" TV channel 23 measurements in SSC office, Analog TV Detector

7. Conclusions

7.1 Detector Sensitivity

Field measurements of feature detectors in multiple environments indicates that it can provide high sensitivity. Table 1 provides the minimum detectable signal levels. These levels are well below what is required to detect TV signals (Intel's threshold value is -129 dBm).

Location	Analog TV Signal Minimum Detectable Carrier Signal (dBm)	Digital TV Signal Minimum Detectable Pilot Signal (dBm)
Indoor Office Environment	-131	-110
Suburban	-142	-140
Rural	-141	NA
Isolated	-142	-143

Table 1. Minimum Detectable Signal Levels

7.2 Signal Amplitude Fluctuations

For strong TV signals, the amplitude fluctuations fall between 0 to 20 dB and the fluctuation period is 30 minutes. For weak TV signals, the amplitude fluctuations fall between 0 to 30 dB and the fluctuation period is 10 minutes. Thus, a TV detector should sample the signal for 10 minutes or more to obtain maximum sensitivity.